RO Plant Performance Evaluation

Filter Performance Data

Throughout the 2000 and 2002 irrigation seasons, both filter trains were used interchangeably but not at the same time. During the year 2002 irrigation season, Filter Train #2 was used more often than Filter Train #1, however the two trains produced similar results.

Operating logs containing filter performance data are presented in **Table D.1** and **Figures D.2** and **D.3** of **Appendix D**.

RO Performance Data

Initially, the RO demonstration plant was designed to recover 70% of the feed water, while removing as much as 95% of the total dissolved solids. Because the quality of the feed water from the North and South Wells was better than that from the tile drain system, the recovery was increased to 75%. TDS removal averaged 97% throughout the life of the project. Tabulated performance data for the RO system can be found in **Appendix E**.

Normalized Flux Variations:

There are two primary standards of performance for RO systems: flux and salt rejection. Temperature and the salinity of the feed water affect flux and salt rejection. It is necessary to normalize the data to standard conditions in order to obtain a realistic evaluation of the performance of the system.

Flux is a measure of the amount of permeate (desalted water) produced per square foot of membrane surface per unit of time. It is typically reported in gallons per day per square foot of membrane area (gfd). When comparing different membranes, specific flux is typically reported[2]. This is the flux produced by 1 psi of net driving pressure. Specific flux typically increases by about 3 percent per degree Celsius. This is because as the temperature of the water increases, its viscosity decreases. Normalized permeate flux is reported as specific flux at 25 degrees C.

[2] A simplified definition of *net driving pressure* is the pressure available to drive water (permeate) through the RO membrane.

Salt rejection describes the amount of salt that the membranes prevent from passing into the permeate. Salt rejection is impacted by temperature, but to a lesser degree than flux.

Normalized flux and salt rejection were monitored throughout the operation of the demonstration plant to determine the condition of the RO membranes. As the membranes fouled, normalized flux dropped. A drop of about 15 percent indicated the need to clean the membranes.

Figure 9 presents the normalized flux and net driving pressure for the RO system for 2002. Ten days after 2002 startup, the demonstration plant experienced a drastic drop in normalized flux from greater than 0.10 gfd/psi to about 0.08 gfd/psi. Inspection revealed a green algae-like substance in a rotometer (flow measuring device). Bio fouling was suspected, and the membranes were cleaned using detergent and citric acid.

Shortly after startup, a well water quality analysis was received. The report indicated a better feed water quality than observed in 2000 when the feedwater for the plant was taken from the tile drain system. Subsequently, the RO recovery rate was increased from the 50% achieved in 2000 to 70%.

On day 30, the second new well was brought online. It appeared that that well initially produced a significant amount of sediment. Some of the materials got through the filters and entered the RO membranes, reducing the normalized flux. The membranes were chemically cleaned[3] on day 37, and the flux recovered.

On day 56, the pH/temperature analyzer probe was replaced. Prior to the replacement, the operator was reporting temperatures from the conductivity/temperature probe. Afterward, the operator reported temperature from the pH/temperature probe.

Based on field observations, the pH/temperature probe read in a range of 1.0 to 1.5 degrees Celsius higher than the conductivity/temperature probe. This led to an adjustment of the normalized flux value, reducing it to approximately 0.080 gfd/psi.

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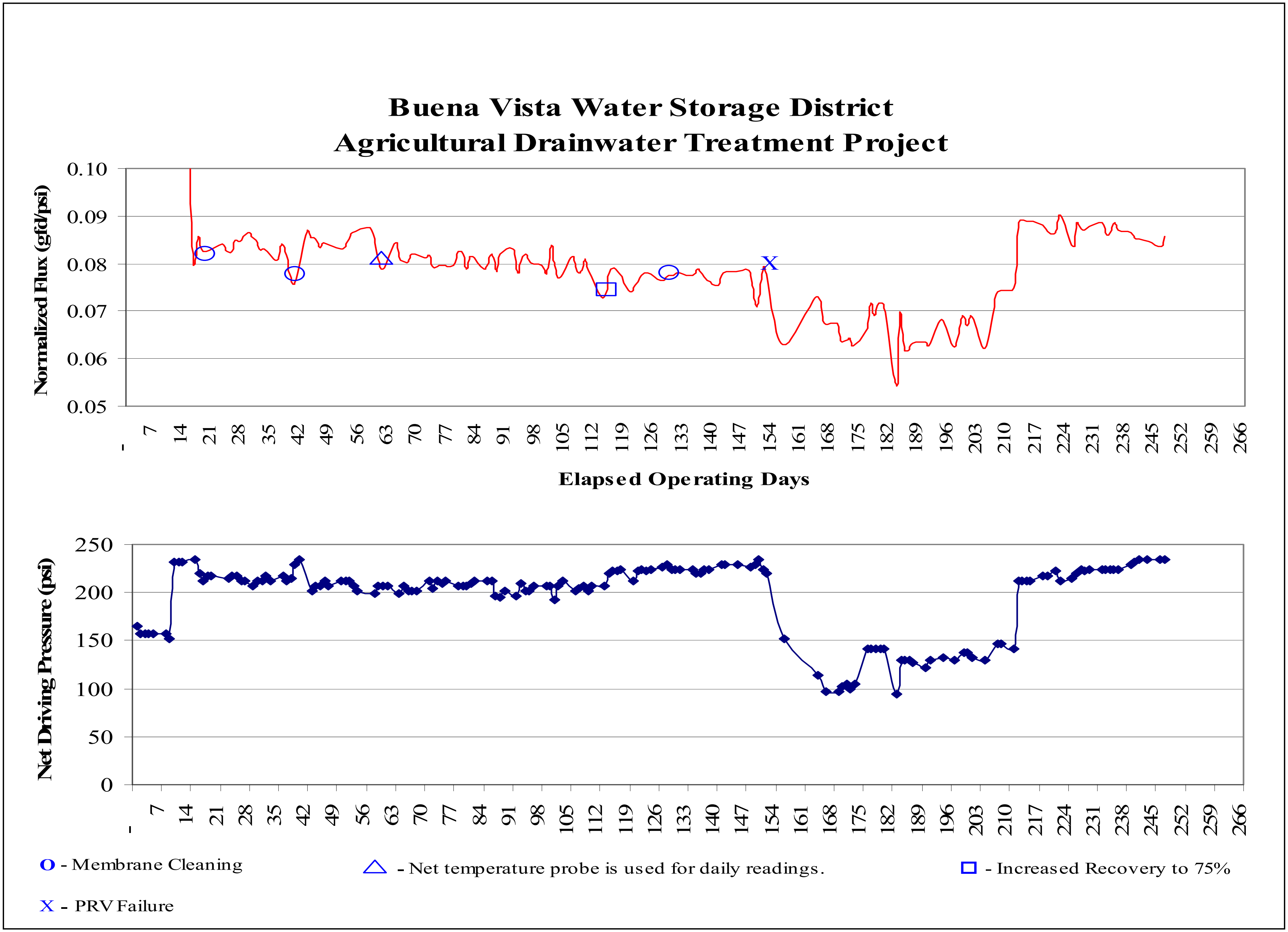
[3] Chemical cleaning consisted of a detergent cleaning and a low pH cleaning. The former includes cleaning with soap (in this case, Tide laundry detergent) to get rid of the organics, while the latter includes adding citric acid to get rid of the mineral scales.

On day 111, the recovery was increased from 70% to 75%. The normalized flux had slightly decreased by this point, but then remained steady at 0.077 gfd/psi. On day 124, due to a decreasing normalized flux, the membranes were chemically cleaned. The cleaning had no effect on normalized flux. However, the recovery rate remained at 75% (producing 15 gpm permeate).

On day 152, a sizeable RO pressure drop was noticed as both the flowrates and the recovery sharply declined. At this point, the normalized flux had dropped to below 0.070 gfd/psi. Initial thinking was that the feed pump had a mechanical failure, however, further probing proved that the pressure relief valve had failed to seat properly. The valve failure was causing the plant to recycle concentrate.

Figure 9: Normalized Flux 2002



On day 208, the pressure relief valve was replaced and the RO pressures as well as the flowrates and recovery rate returned to levels seen before the pressure drop. The normalized flux increased to an average of 0.087 gfd/psi and remained near this level through the end of the project.

Figures 10 through **14** present additional operating data for the plant.

Figure 10: Demonstration Plant Flowrates 2002

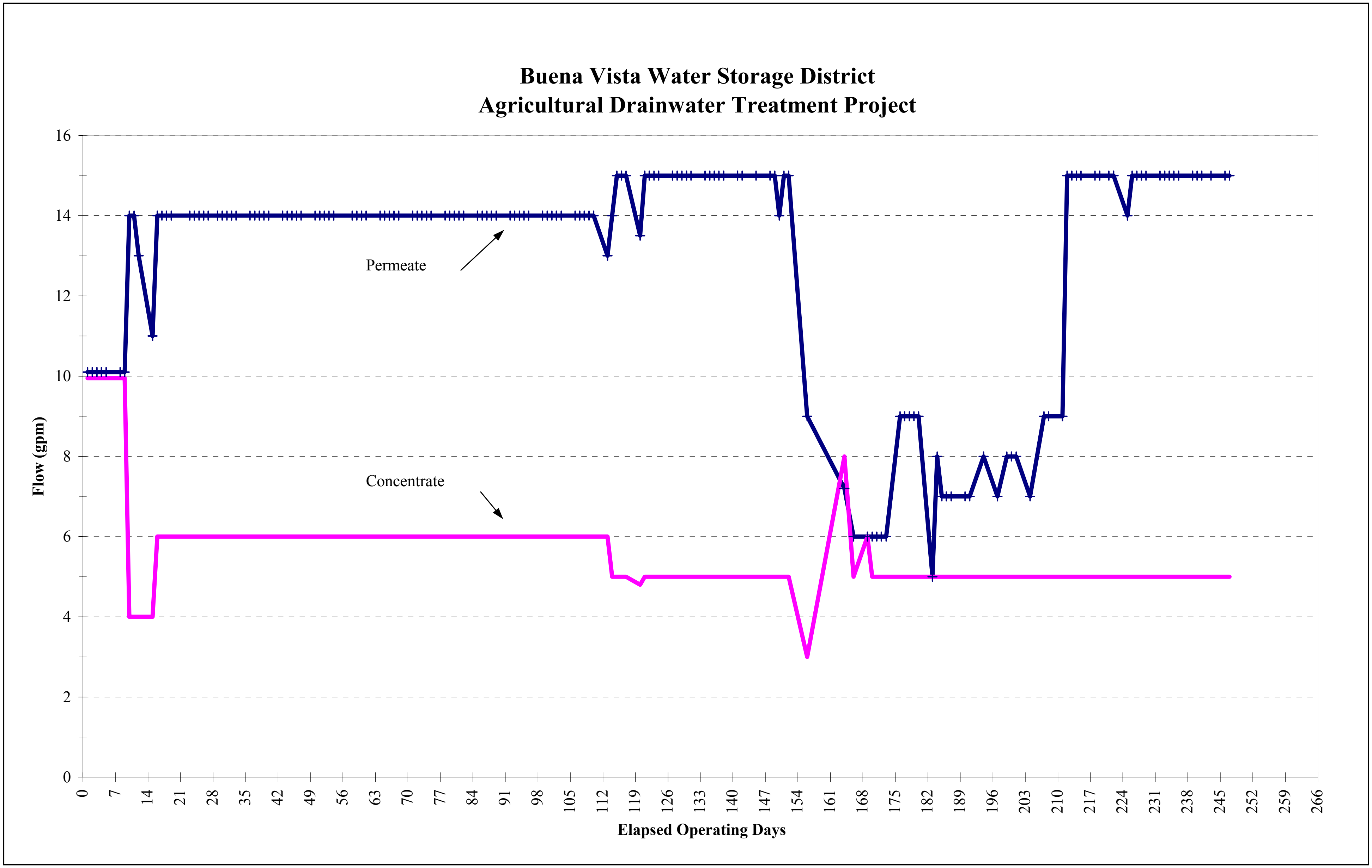


Figure 11: Demonstration Plant Pressures 2002

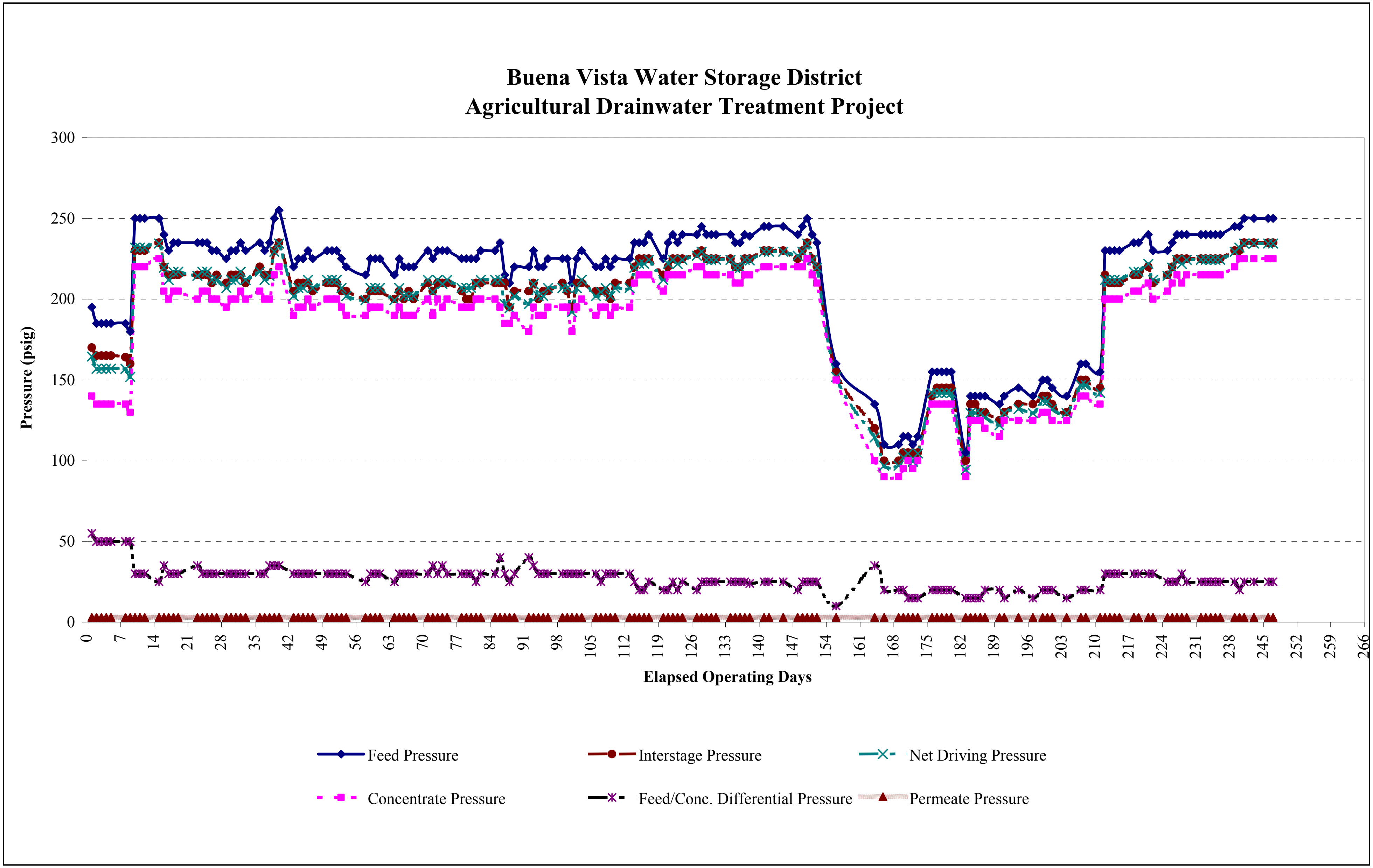


Figure 12: Electrical Conductivities 2002

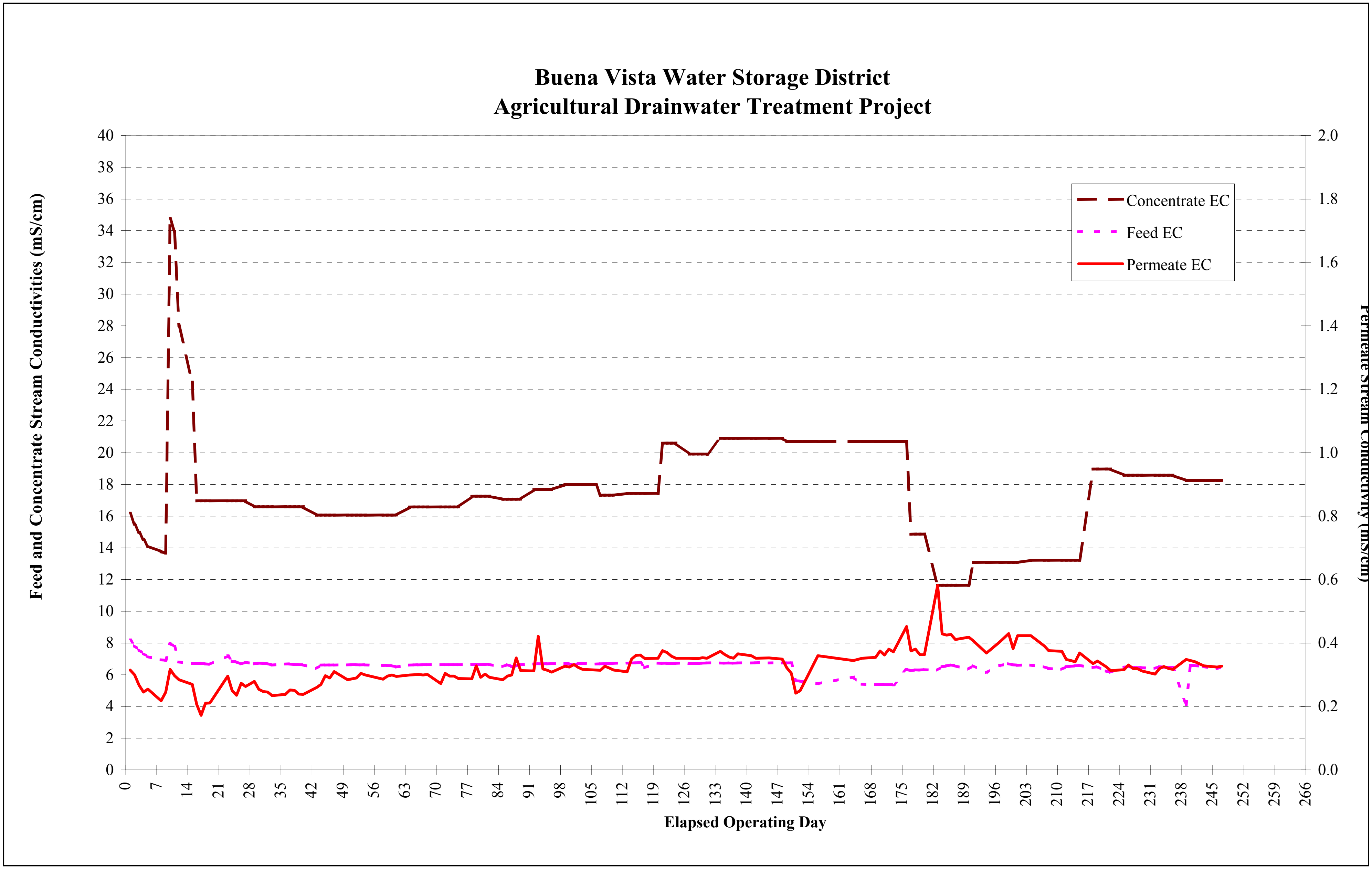


Figure 13: Permeate Electrical Conductivities 2002

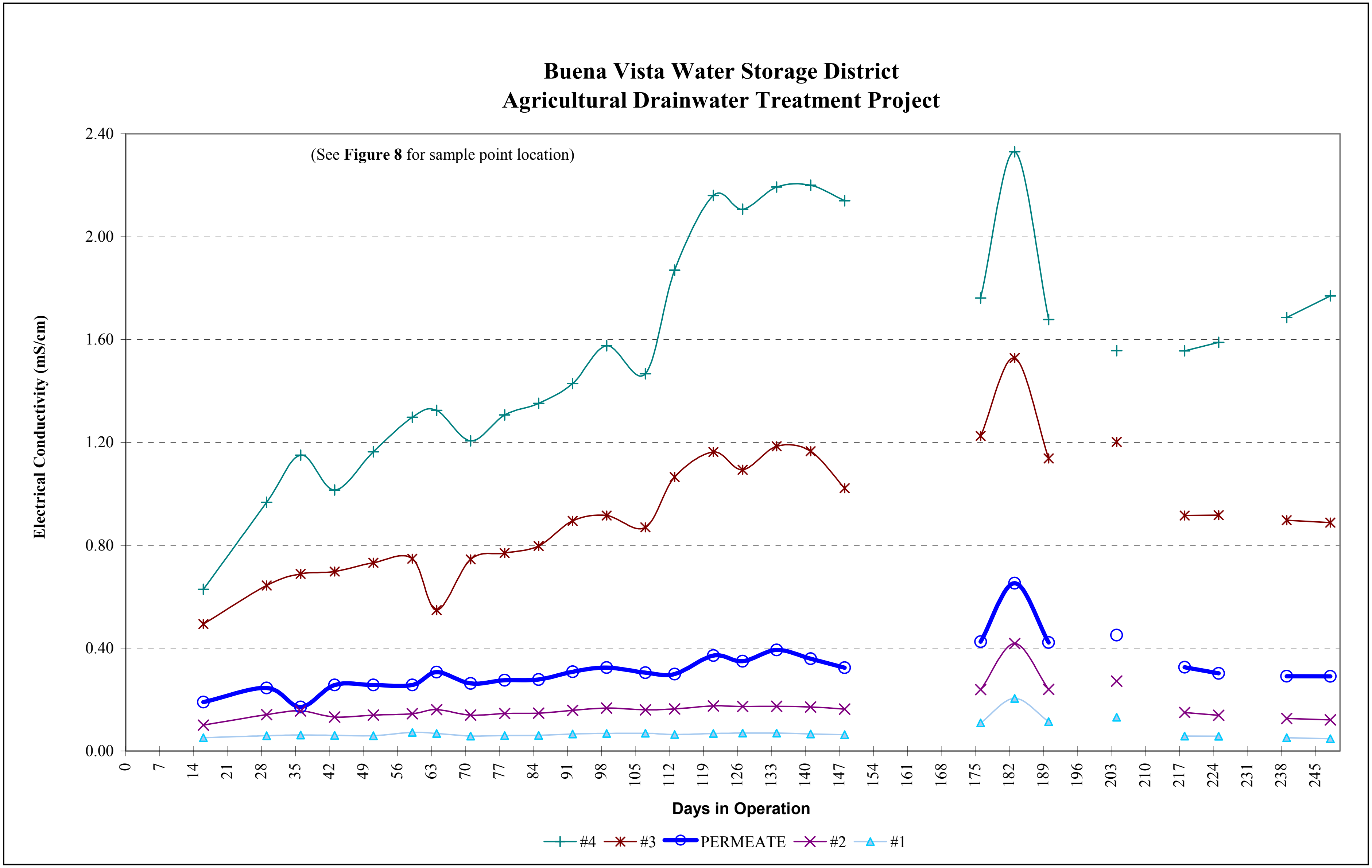
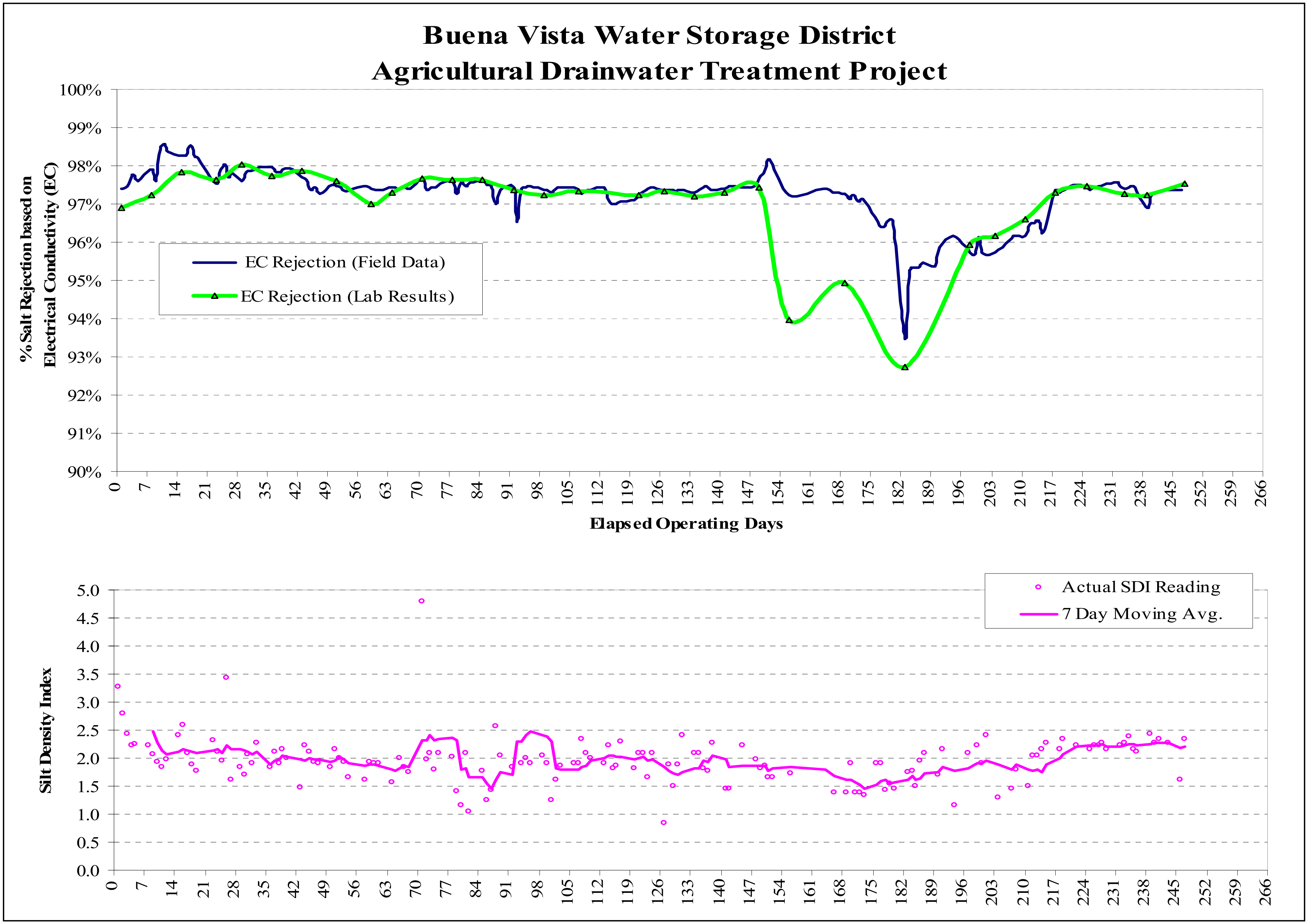


Figure 14: Demonstration Plant Salt Rejection 2002



Laboratory Water Quality Analysis

Figure 16 shows the TDS (salt) rejection rate consistently stayed between 97%-98%. In **Figure 16**, the rejection rates are differentiated by ionic species. As expected the RO membranes are more effective at rejecting divalent[4] ions such as calcium (2+), magnesium (2+), and sulfate (2-), versus the monovalent ions such as sodium (1+), chloride (1-), and bicarbonate (1-). The majority of the ions varied slightly in terms of their rejection; rejection rates were not dependent upon which filter train was used.

Evaluating RO Membrane Salt Rejection

Besides using operating data to formulate values such as normalized flux and process stream conductivities or driving pressures to characterize the health of the RO membranes, analytical lab data can also be used to measure the effectiveness of the RO membranes. The analytical recovery and rejection rates of TDS from the process streams were used in this study.

The TDS rejection rate is defined as the ratio of the permeate TDS concentration divided by the average of the filtrate and concentrate TDS concentrations. Likewise, rejection rate for each ionic species is also defined as the ratio of the permeate ionic species' concentration divided by the average of the filtrate and concentrate ionic species' concentrations. These are typically expressed as *percent rejection.*

TDS Analytical Recovery is a mass balance calculation. It is defined as the ratio of the mass (pounds) of material that exits the membranes over the mass of material that enters the membranes. In this case, it is the sum of the mass of the TDS found in the permeate and the

[4] TDS results from the dissolving of minerals such as calcium sulfate (gypsum) and salt (sodium chloride). When the minerals dissolve, they separate into the *ions* that compose them. For example, calcium sulfate consists of calcium ions and sulfate ions. Sodium chloride consists of sodium ions and chloride ions. Ions are electrically charged either positively or negatively. Ions can have a single charge (monovalent) or multiple charges (multivalent). Divalent ions have twice the electrical charge of monovalent ions. Sodium and chloride are examples of monovalent ions. Calcium and sulfate are examples of divalent ions.

concentrate divided by the mass of the TDS found in the filtrate. A value significantly different than 100% indicates an error in measurement. Error sources include incorrect flow rate measurement, improper sampling technique, and analytical errors (See **Figure 15** for values relating to the TDS Analytical Recovery).

Figure 15: TDS Rejection 2002

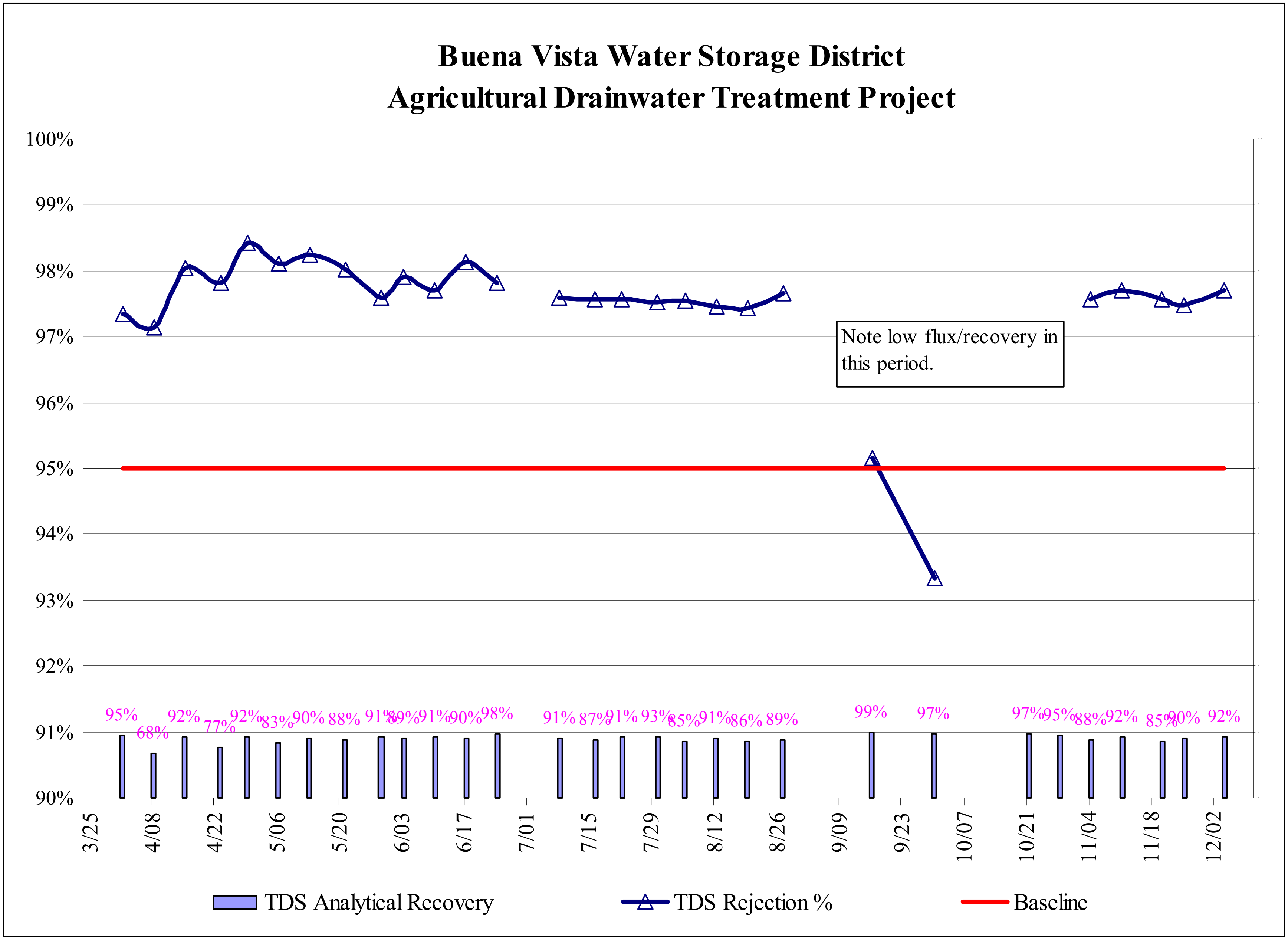
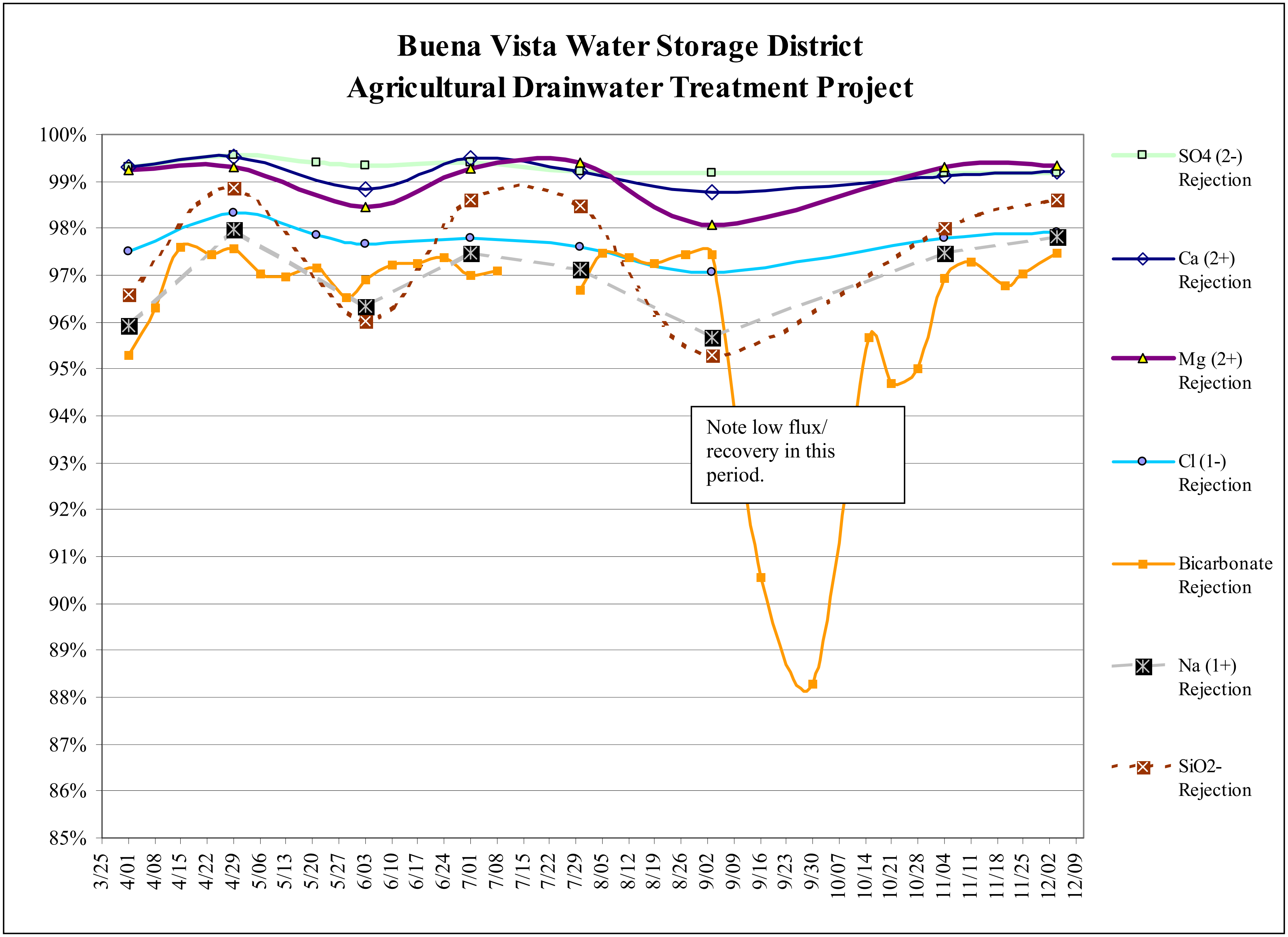


Figure 16: Ion Rejection 2002



Total Organic Carbon Results

Total organic carbon (TOC)[5] concentration in the feed water varied throughout the testing period. The RO process typically provided over 80% rejection of organics.

Typical TOC concentration in the feed water ranged between 5.0 and 8.0 mg/L. During the start of the irrigation period on June 4th, 2002, a value of over 10.0 was observed, however, this high TOC concentration was not seen again. TOC in the feed water promotes bio fouling of the RO membranes. An increase in TOC will lead to more downtime, as the plant would have to be idled more often for membrane cleaning.

Alum coagulation was used as a supplement to the filter vessels. Injection began April 15th, 2002, two weeks after startup. By comparing the TOC values between the Feed and Filtrate Streams in **Figure 17**, it can be seen that filtration did not appreciably reduce TOC in the demonstration plant's feedwater.

[5] TOC is the sum of all forms of organic carbon found in the water. Organic carbons are combinations of carbon and hydrogen sometimes associated with other elements such as chlorine, oxygen, etc. Examples of substances that make up TOC include natural plant and animal materials, herbicides, fertilizers, insecticides, petroleum related substances, etc.

Figure 17: Total Organic Carbon Rejection 2002